Pyrogen - Delay Ejection Device

(Pyro-DED)

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Purpose

The **Pyrogen-DED** is intended to be a simple, motor mounted, pyrotechnic-based device for use as part of a rocket parachute recovery system. The Pyrogen-DED described here is intended to be versatile such that it can be employed with nearly any Amateur Experimental rocket motor. To be used with a given motor, it is only necessary to have an appropriate threaded hole in the motor bulkhead to accept the unit.

Functional Description

The Pyrogen-DED consists of three distinct elements integrated into a single unit. As such, the function of the Pyrogen-DED is threefold:

1 - Provide a delay period & smoke trail while rocket coasts to apogee following motor burnout. This function is performed by the **Delay Grain.**

2 - Provide a pressurization force to deploy a recovery device. This function is performed by the **Ejection Charge**.

3 - Aid in rapid ignition of the motor propellant. This function is performed by the **Pyrogen**. Another important function of the Pyrogen is to reliably ignite the Delay Grain.

Physical Description

The Pyro-DED is illustrated in Figure 1. It consists of a one-piece unit machined from hex steel bar stock. It has two integral cavities separated by a restrictor orifice. The lower cavity holds the Delay Grain and Pyrogen charge, and the upper cavity holds the Ejection Charge. The Delay Grain is cast in place, the Pyrogen charge is press-formed in place, and the Ejection Charge is a finely granulated powder contained by a frangible cap made from aluminum foil tape. The lower portion of the Pyro-DED has an integral male fitting with taper threads. This end screws into the rocket motor bulkhead. The upper portion is a straight shank which is meant to be inserted into a hole in a rocket vehicle thrust bulkhead and sealed to a gas-tight condition using an o-ring or duct seal.

The Pyrogen incorporates a conical shaped grain of "Grey Powder" with a binding agent. Grey Powder is a hot-burning pyrotechnic material similar in composition to Black Powder

The Delay Grain is comprised of a cast-in-place formulation of Potassium nitrate, epoxy and iron oxide.

The Ejection Charge is a pyrotechnic material that, when ignited, produces a large volume of hot gases. Normally "Crimson Powder" is used, although conventional Black Powder may be a suitable alternative.

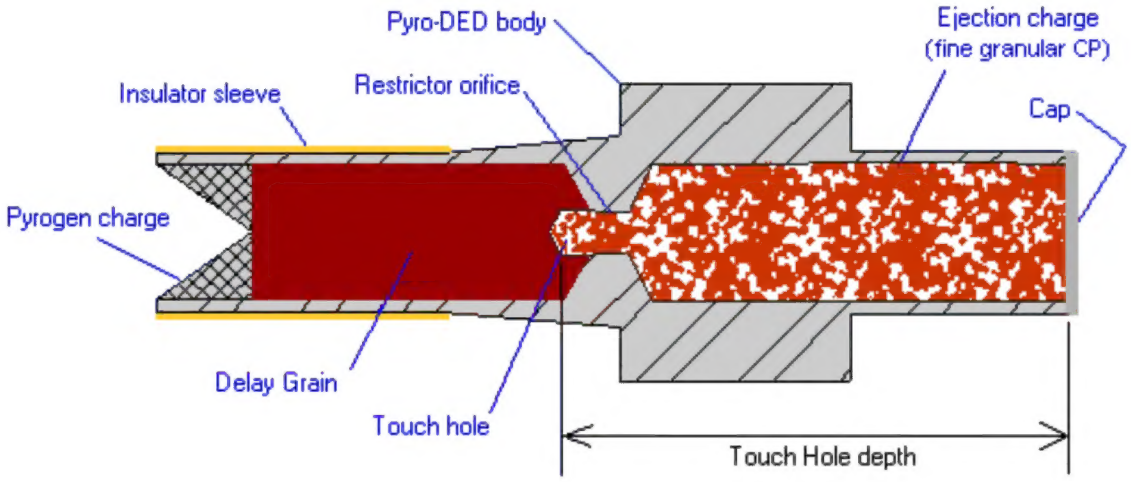

Figure 1 -- Pyro-DED

The current Pyro-DED design provides a maximum delay of approximately 13 seconds (exact delay may vary depending on brand of epoxy used). The delay period can be shortened as required. The delay period is fine tuned by choosing the depth of the "touch hole" drilled into the Delay Grain.

The Pyro-DED holds up to 1 gram of Ejection Charge material, which is more than sufficient for a piston-based ejection system as illustrated in Figure 5.

The **Insulator Sleeve** provides thermal protection to the Delay Grain to prevent the absorption of heat produced by the motor. The adverse effect of heat absorption would be a reduced delay period. The Insulator Sleeve is made of heavy paper and is replaced after each use.

Fabrication

The Pyro-DED is normally fabricated from mild steel (e.g. C1018) hexagon stock. Aluminum alloy may be used, but heat damage to the device may occur. However, for single-shot (throwaway) application, aluminum is suitable. An advantage of aluminum is ease of machining and exceptionally low mass. Steel has the advantage of unlimited life.

The hex stock may be ½", 9/16" or 5/8" (12, 14 or 16 mm). Obviously, ½" stock will result in the lowest weight. Fabrication is quite simple using a metal lathe. Typically, several units are made at once. Having more than one unit allows for more efficient reloading.

Figure 2 illustrates the dimensions of the device. The two cavities are drilled first, and then the orifice is drilled. A "center bit" should be used to start the holes to ensure they are drilled concentrically. The outer profile is then turned and finally, the bottom shank is threaded. All sharp edges are then broken with a slight chamfer.

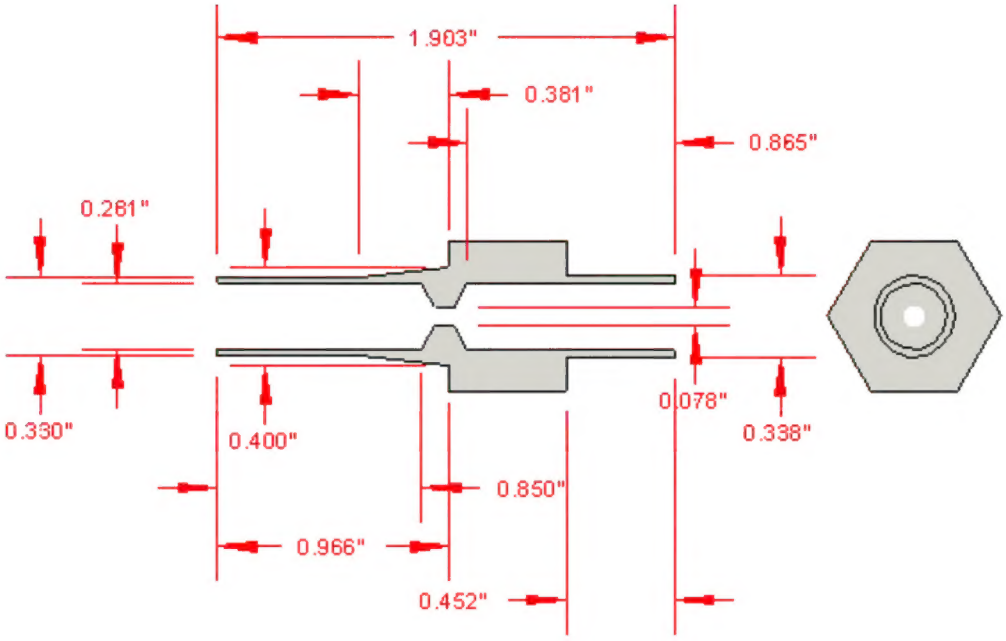

Figure 2a -- Dimensions of Pyro-DED (inches)

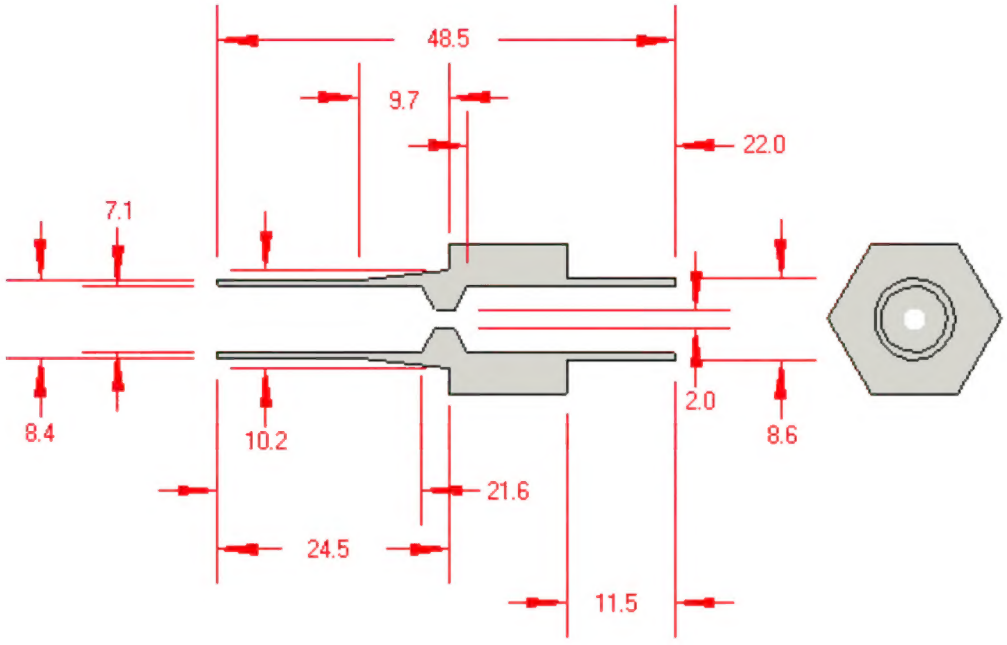

Figure 2b -- Dimensions of Pyro-DED (mm)

Operation

The Pyro-DED is meant to be used with a motor igniter that fires an upward flame, such as that shown in Figure 3. This ensures quick ignition of the Pyrogen charge, which simultaneously ignites the motor propellant grain and the Delay Grain. This system was developed to ensure reliable ignition of the Delay Grain even when used with very short burn time motors, such as the A-100M. Note that with longer burn time motors (say, one second or longer) it *may* be possible to omit the pyrogen and still have reliable operation of the Pyro-DED. This will be investigated at a future date.

The Pyrogen charge is made with a conical-shaped depression that forms the initial burning surface. This feature helps to facilitate ignition of the motor propellant grain by producing a "fan-like" flame, and helps ensure reliable ignition of the Delay Grain by maximizing exposure of the Delay Grain material to the heat of Pyrogen charge combustion.

As soon as the Pyrogen begins to burn, the Delay Grain simultaneously begins burning. Burning of the Delay Grain progresses in a linear manner, producing the delay period and smoke track. Note that the smoke track will be quite faint and is usually only visible as the rocket slows near apogee. Once the flame front reaches the touch hole, the Ejection Charge material present within the hole ignites and instantly spreads to the main body of Ejection Charge. This produces high pressure within the cavity, which ruptures the frangible foil cap and pressurizes the rocket body compartment. The orifice serves as a restrictor, minimizing pressure loss through the motor.

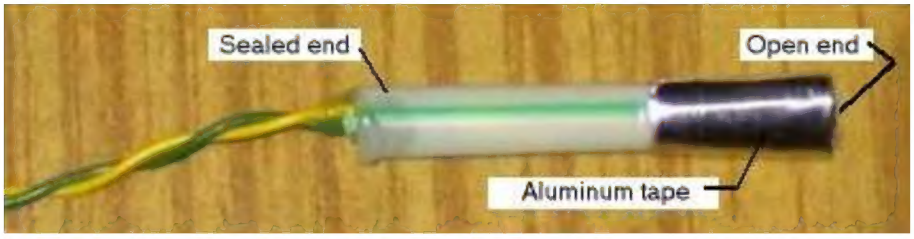

Figure 3 – Example of "upward firing" igniter

Reusability

A Pyro-DED fabricated from steel may be reused an unlimited number of times. After use, it is cleaned with hot water & soap. A cotton-swab is used to clean the inside cavities. The orifice is cleaned with a toothpick or wire. The final step in cleaning is rinsing the device with hot water and immediately drying, internally & externally, with paper toweling.

Preparation of Compositions

The compositions of the Delay Grain, Pyrogen Charge and Ejection Charge are given in Table 1.

Delay Grain		
Constituent	*Mass Percentage*	*Notes*
Potassium Nitrate	65	[1]
Red Iron Oxide (RIO)	5	
Epoxy	30	[2]
[1] Finely ground		
[2] West System or similar two-part epoxy		
Pyrogen Charge		
Constituent	*Mass Percentage*	*Notes*
Potassium Nitrate	78	[3]
Sulfur	17	[3]
Charcoal	5	[3]
Neoprene contact cement	See note	[4]
[3] Finely ground		
[4] Minimum amount to fully wet the powder		
	Ejection Charge	
Constituent	*Mass Percentage*	*Notes*
Potassium Nitrate	55	*See separate article on Crimson Powder*
Ascorbic Acid	40	
Red Iron Oxide (RIO)	5	

Table 1

Delay composition:

A binary mixture of Potassium Nitrate and Red Iron Oxide is prepared first. A batch of this mixture is typically prepared that will serve for several reloads of the Pyro-DED. A suggested batch size is 70 grams, which is enough for more than 20 reloads. A mass of 65 grams of finely ground Potassium Nitrate and 5 grams of Red Iron Oxide is weighed out and combined into a small Tupperware container. It is very important that these two constituents be **very well blended**. This is best performed with the addition of a half dozen glass or natural aquarium stones, then blending for two or more hours with the container mounted (using rubber bands) on a rotating mixer (typical 30 RPM). This binary mixture should be stored in a dry

location. Note that this binary mixture is non-combustible. The epoxy component is added later.

Pyrogen composition:

The Pyrogen composition consists of "Grey Powder" formulation with neoprene contact cement added as a binder and combustion enhancer. Only a small amount of Pyrogen composition is needed for each reload. As such, a batch of 10 grams of Grey Powder should be prepared, which is enough for about 20 reloads. Using an accurate scale, 7.8 grams Potassium Nitrate, 1.7 grams Sulfur and 0.5 grams of charcoal are weighed out and combined. The mixture is first well blended, and then a small amount of water is added to make a uniform paste. The wet mixture is then spread out onto a sheet of aluminum foil and allowed to thoroughly dry in a warm, dry, secure location. The product is then ground to a fine powder using a mortar & pestle. The product should be stored in a suitable sealed container. Note that this product is **combustible** and appropriate precautions and care must be exercised in preparation, handling and storage. No more than 10 grams should be prepared at any one time. The neoprene contact cement is added later.

Ejection Charge:

"Crimson Powder" (CP) is the best choice for Ejection Charge material. Compared to conventional Black Powder, CP is more powerful, cleaner burning and simpler to prepare. CP is similarly very fast burning. Preparation of the Crimson Powder Ejection Charge is described in a separate document. For use in the Pyro-DED, the CP **must be a fine granular form**, This form burns rapidly due to the large surface area of the granules. The particles must be fine enough to fill the 5/64" (2 mm) orifice. As such, the CP must be sifted to remove any particles that could be large enough to block the orifice. A fine nylon-mesh kitchen sieve works well. Note that this product is **highly combustible** and appropriate precautions and care must be exercised in preparation, handling and storage. No more than 10 grams should be prepared at any one time. This is enough for 10-20 reloads.

Loading the Delay and Pyrogen Charges

It is recommended, for convenience and to reduce wastage, to load several Pyro-DEDs at any one time. The Delay Grain is cast in place first of all. Referring to Table 2, the required amount of the powdered binary delay mixture is weighed out, then the required amount of two-part epoxy is prepared, and mixed well with the powder. The resulting product will be fairly thick, similar to peanut butter in consistency. In order to effectively load this mixture into the cavity of the Pyro-DED, the Pyro-DED is first heated using a hot-air gun or alternatively, a hairdryer set to maximum. The body of the Pyro-DED is briefly heated such that it can still be held with bare fingers. With the use a toothpick, the mixture is loaded, a little at a time, tapping the Pyro-DED against the table to facilitate the flow of the material. Once warmed, the mixture will attain a lower viscosity and flow

readily and fill out the cavity. Enough material is added until it is at a level 0.2 inches (0.5 mm) from the open end of the cavity. This is to allow room for the Pyrogen charge.

If the Delay Composition has a tendency to flow out of the Pyro-DED through the orifice, a round toothpick (or similar) can be inserted into the orifice from the other end. It is important to remember to remove the toothpick after the Delay composition begins to set (typically after ½ hour or so).

No. of Pyro-DEDs	Pot.Nitrate+RIO (grams)	Epoxy (grams)
1	0.9	0.4
2	1.6	0.7
3	2.4	1.0
4	3.2	1.4
5	4.0	1.7
6	4.8	2.1
7	5.6	2.4
8	6.4	2.7
Note: Includes 15% for wastage.		

Table 2

After the Delay Composition has set, the Pyrogen charge is loaded. To determine the amount of Grey Powder needed, the cavity is filled with the powder. The powder is then poured onto a mixing surface (a piece of polyethylene sheet cut from a discarded plastic bottle works well) and a small amount of contact cement is added. Only enough should be used to fully wet the powder. The wetted powder is then pressed into the cavity and packed using a round toothpick with the sharp end cut off (or similar such tool). The mixture is allowed to set for a few minutes, then using the conical forming tool (Figure 4), the mixture is firmly pressed until the tool seats, then withdrawn immediately. A uniformly shaped conical depression should result (step is repeated if necessary).

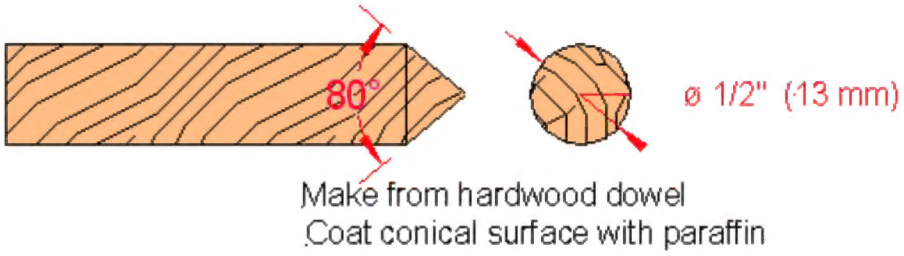

Figure 4 – Conical forming tool for Pyrogen

Creating the Touch Hole

After casting the Delay Grain, the restrictor orifice will be partly filled with Delay Grain material. Once the Delay Grain has fully cured, this material must be removed, and concurrently, a "touch hole" must be created which extends into the body of the Delay Grain (see Fig.1). The purpose of the touch hole is twofold. One, to fine-tune the delay period, which is dependant upon the depth of the touch hole, and two, to serve as a "primer cavity" for the Ejection Charge material.

To create the touch hole, a drill bit of 5/64" (2 mm) diameter is mounted in a pin vise (or drill chuck) such that the desired depth can be drilled. The Delay Grain material is fairly soft, and as such, manual drilling is recommended. The **minimum** depth of the touch hole (1" or 25 mm) is such that the hole extends past the orifice and into the body of the Delay Grain. This is to ensure reliable ignition of the Ejection Charge. Table 3 provides a guideline as to theoretical delay period versus depth of touch hole. These times may differ if an alternate brand of epoxy is used in the Delay Grain composition. Delay times shown are based on a nominal burn rate of 1.4 mm/second.

It is important to note that for safe rocket recovery, the delay period is not critical. The "window" of opportunity to deploy a parachute is quite generous, and generally covers 5 seconds or more. The parachute may be safely deployed at any time when the rocket begins to slow as it approaches apogee, it may deploy as the rocket arcs over at apogee, or as the rocket begins to descend. It is best, therefore, to target "time to apogee" when choosing the delay period which would typically be based on simulation software prediction.

Touch hole Depth (inch)	Theoretical Delay (sec)	Touch hole Depth (mm)	Theoretical Delay (sec)
1	12.8	25	13.0
1.1	10.9	27	11.6
1.2	9.1	29	10.2
1.3	7.3	31	8.8
1.4	5.5	33	7.3
		35	5.9

Table 3

Loading the Ejection Charge

Safety glasses must be worn at all times when handling and loading Ejection Charge material. With the aid of a plastic drinking straw with one end cut at a bevel, a small amount of sifted, **fine granular** CP is repeated loaded into the Pyro-DED cavity. The body of the Pyro-DED should be tapped on the outside with a non-metallic object to help settle the material. Fill as required. **Do not pack or compress the CP**, as it must be loose in order to burn very rapidly to develop the needed pressure for ejection. If less than a full charge (1 gram) is being loaded, the void should be filled with glass wool. The top edge of the Pyro-DED is then cleaned with alcohol or lacquer thinner, and a "cap" cut from aluminum foil tape is installed to seal the cavity. The cap can be initially cut larger than needed, and then trimmed with a hobby knife.

Insulator Sleeve

The Insulator Sleeve is made from rolled "tagboard". This is heavy paper typically used for posterboard or file folders. To make the Insulator Sleeve, a piece of tagboard of ½"x 2-1/4" (13 mm x 57 mm) is cut out. The paper is then **tightly** rolled around the shank of the Pyro-DED body that holds the Delay Grain. A dab of white glue is applied to the overlapping region. A spring clamp may be used to hold the seam while the glue sets (usually 5 minutes or so). The sleeve is then removed from the shank. Typically several Insulating Sleeves are made at a time, and kept for future use.

Installation in the Rocket Motor

The bulkhead of the motor is required to have a threaded hole to accept the Pyro-DED unit. The thread type is 1/8" NPT (National Pipe Thread) or the metric equivalent. This is a **taper thread** that provides an effective pressure-tight seal when used in conjunction with a suitable sealant material.

To install the Pyro-DED unit, the male threads of the unit and the female threads of the bulkhead are coated with "pipe joint sealant". Alternatively, teflon tape may be used, although the resulting seal may be less reliable. The unit is then screwed into place using a wrench to tighten to a snug fit, being careful not to over-tighten. The Insulator Sleeve is then slipped into place, using a small dab of glue, if needed, to retain it.

It is important to remember to install the motor igniter such that it contacts the Pyrogen. The igniter should be held in position by some means to avoid it from "kicking out" of the motor once the igniter fires. This may be accomplished by packing a ball of glass-wool into the nozzle throat to fix the igniter leads in position (when the motor fires, the ball of glass-wool and spent igniter will be ejected).

Arrangement of Pyro-DED Equipped Motor in a Rocket

One method of parachute deployment utilizing a Pyro-DED equipped rocket motor is illustrated in Figure 5. This method has been used with good success for the *SkyDart* rocket. This design make very efficient use of the pressure generated by combustion of the Ejection Charge and as such, requires only a half-charge of Crimson Powder. With this particular design, "heat-proof wadding" is not required, as the parachute is never exposed to hot ejection gases.

It is important to note that, for any particular design, the motor must be effectively constrained to prevent it from ejecting out the rear of the rocket when the Ejection Charge fires.

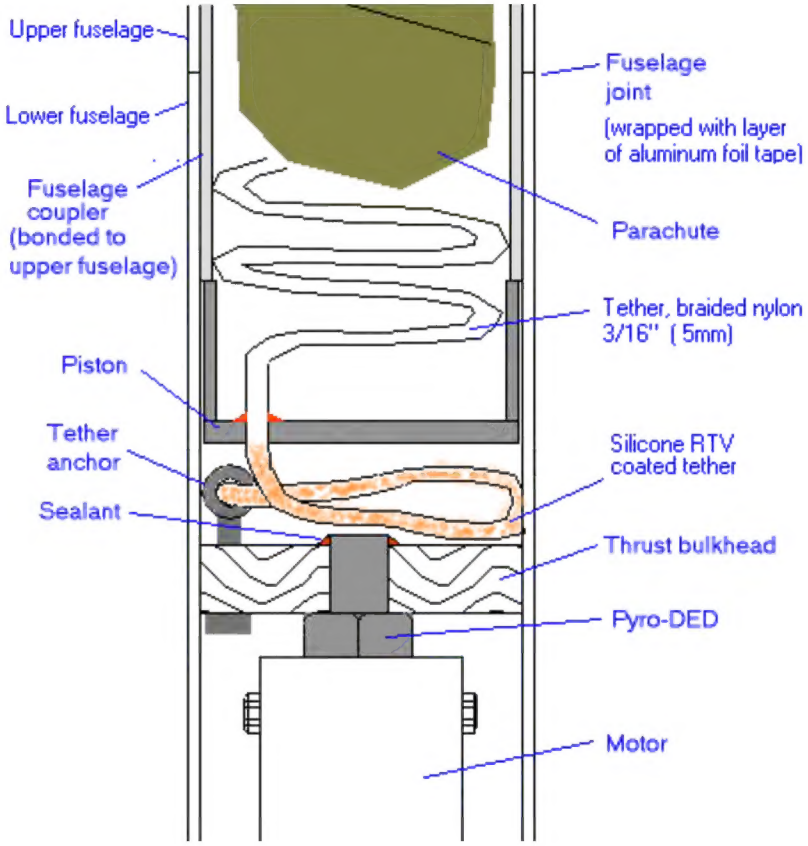

Figure 5 – Example Pyro-DED installation and parachute deployment system